NATURE OF THE INFLUENCE OF THE UNIT REYNOLDS NUMBER
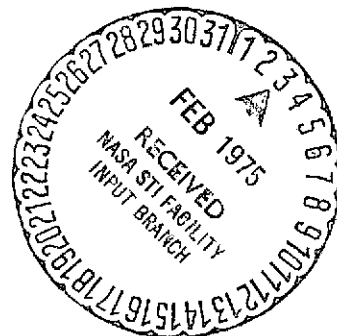## ON SUPERSONIC BOUNDARY LAYER TRANSITION

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16. Abstract

The experiments were conducted in several wind tunnels freestream Mach numbers ranging from 2 to 6 and unit Reynolds numbers of (10 to 60) by 1,000,000/m. In this range of flow parameters, a qualitative correlation was observed in the changes in transition Reynolds number and pressure pulsations with increasing unit Reynolds number. A correlation parameter accounting for the intensity and scale of disturbances is proposed for generalizing available experimental data. It is shown that the effect of the unit Reynolds number is equivalent to the combined influence of acoustic disturbances and of the leading-edge bluntness of the model on transition.

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NATURE OF THE INFLUENCE OF THE UNIT REYNOLDS NUMBER ON SUPERSONIC BOUNDARY LAYER TRANSITION

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An analysis is made of experimental data on the influence /150** of the so called unit Reynolds number R_{01} on supersonic boundary layer transition of a plane plate, obtained in wind tunnels in a wide range of the flow parameter changes $M_\infty = 2 \div 6$ and $Re_1 = (10 \div 60) \cdot 10^6$ м. In the studied range of flow parameters there is a qualitative agreement in the change of the transition Reynolds number Re_3 and the pressure pulsations with an increase in the unit Reynolds number Re. A correlation parameter is proposed which takes into account the intensity and scale of perturbations, which makes it possible to generalize the existing experimental data.

It is shown that the effect of the unit Reynolds number is the result of the concurrent influence on the transition of the accoustic perturbations and the degree of blunting of the model leading edge.

For several years there have been discussions in the literature upon the influence on the boundary layer transition of a dimensional parameter, which according to established terminology changes by the unit Reynolds number $Re_1 = (U/\nu)_\infty$. Several researchers [1 — 8] have shown that there is an increase in the transition Reynolds number Re_* with an increase in the unit Reynolds number. Detailed summaries of the

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**Numbers in the margin indicate pagination in the original foreign text.

experimental data about the influence of this dimensional parameter on the transition are given in [1, 2]. It may be noted that the experimental data on this problem published at the present time are frequently contradictory, and it has still not been established whether to take into account the influence of this parameter, or to disregard it.

The greatest difficulties are encountered in studying the laminar boundary layer transition into a turbulent layer. These difficulties are due to the mutual influence upon this phenomenon of different factors. At the present time, it is not possible to separate the influence of a certain factor completely.

In [3] the authors have called attention to the fact that the influence of the unit Reynolds number is a function of the magnitude of this parameter in varying degrees. At large Re_1 values the increase in the transition Reynolds number is reduced or is ended altogether. According to the hypothesis in [4] regarding the influence on the aerodynamic noise transition, measurements were made of the pressure pulsations on the wall of an operational wind tunnel T — 325 [9] at M_x = 3.0 and 4.0 in a wide range of changes in the unit Reynolds number. The results of these measurements showed that there is a qualitative agreement in the transition Reynolds number change and the change in the pressure pulsations with an increase in the unit Reynolds number, i. e., with a decrease in the level of acoustic perturbations generated by the turbulent boundary layer at the walls of the operational section of the wind tunnel, and there is an increase in the transition Reynolds number where the intensity of the perturbations depends slightly on the Re_1 and the Re_* no longer changes.

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A similar situation is also observed in a T-313 wind tunnel with large dimensions of the operational section. This provides a basis for assuming that the change in the transition Reynolds number with an increase in Re_1 basically is caused by the generation of accoustic perturbations by the turbulent boundary layer of the wind tunnel walls. The most reliable verification of this assumption is provided by data on the transition obtained in wind tunnels with a laminar boundary layer on the operational section of the walls. However, in the overwhelming majority of supersonic devices the boundary layer on the walls of the operational sections is turbulent and generates accoustic perturbations.

It was shown in [3, 4] that, other conditions being the same, the transition Reynolds number also depends on the dimensions of the operational section of geometrically similar devices. This may be related to the fact that the scale of perturbations in any device is proportionate to its dimensions. Consequently, when analyzing the experimental data the spectral composition of the perturbations must be taken into account.

It was shown in [10] that, in addition to the regular factors which influence the transition, important additional parameters are the dimensionless frequency* or wavelength $\omega\lambda$ and orientation 0, which characterize the spectrum of the perturbations. The study [11] developed a theory, according to which the transition is determined not only by the intensity but also the scale of the perturbations of the external flow

$$Re_t = f\left[\frac{u}{l}\left(\frac{L}{l}\right)^{1/2}\right]$$

Here u is the velocity fluctuation, L — characteristic dimensions, l — scale of perturbations.

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*Translator's note: Illegible in foreign text.

It is thus assumed that the transition caused by the turbulence of the basic flow is the result of a brief separation of the boundary layer due to the occurrence within the layer of pressure gradients produced by the pressure pulsations in the external flow. However, the authors still do not have information regarding the spectral characteristics of the perturbations in any supersonic equipment. Nevertheless, this lack of information does not eliminate the necessity of systematizing and generalizing the existing experimental data. When perturbations produced by a turbulent boundary layer of the wind tunnel walls are predominant, it may be assumed that the displacement* of this boundary layer is proportional to the scale of the perturbations. Let us introduce the correlation parameter $(Re_*{}^K)_o/$ *, where $(Re_*{}^K)_o$ is the transition Reynolds number in a boundary layer of a plane plate with a narrow leading edge, Re* — Reynolds number with respect to the displacement thickness of the boundary layer of the wind tunnel walls.   /152

Statistical processing of the transition measurement results has shown that at n=0.25 the scatter of the experimental data does not exceed ±15%. Figure 1 shows the correlation of the existing data on the transition in a boundary layer, obtained in 6 wind tunnels at $M_\infty=3.0$ and $b=0$ (The numbers of the data correspond to the numbers of the wind tunnels, where PP is a plane plate and HC is a hollow cylinder.) It may be seen that the introduction of the correlation parameter makes it possible to generalize the results of measurements in different wind tunnels and to represent them in a form which does not depend on the unit Reynolds number. Consequently, excluding the influence on the leading edge bluntness transition by extrapolating to we may also take into account the influence of the perturbations

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TABLE 1

| PP number	Equipment	Dimensions of working Section, m^2	M		in mm	source	model
1	T-325	0.2×0.2	3.0	11.0÷72.0	0.50÷0.18	authors	PP
2	AEDC PWT-16S	4.88×4.88	3.0	1.9÷4.35	0.0÷0.23	[3]	PP
3	AEDC VKF-D	0.3×0.3	3.0	3.9÷23.5	1.0÷0.09	[4]	HC
4	NASA – Lewis	0.3×0.3	3.0	3.9÷23.5	0.0	[5]	HC
5	AEDC VKF-A	1.02×1.02	3.0	5.9÷23.5	0.0÷0.09	[4]	HC
6	T-313	0.6×0.6	3.0	14.0÷50.0	0.0÷0.10	authors	PP
7	T-313	0.6×0.6	2.5	10.7÷16.6	0.19	authors	PP
8	T-313	0.6×0.6	3.5	10.8÷15.7	0.10	authors	PP
9	T-313	0.6×0.6	4.0	24.0÷60.0	0.10÷0.15	authors	PP
10	T-313	0.6×0.6	5.0	10.8	0.10	authors	PP
11	T-313	0.6×0.6	6.0	10.7÷11.4	0.10	authors	PP
12	T-325	0.2×0.2	2.5	14.0÷40.0	0.10÷0.18	authors	PP
13	T-325	0.2×0.2	3.5	14.0÷60.0	0.10÷0.18	authors	PP
14	T-325	0.2×0.2	4.0	20.0÷50.0	0.05÷0.18	authors	PP
15	AEDC VKF – A	1.02×1.02	5.0	5.9÷23.5	0.033÷0.053	[4]	HC
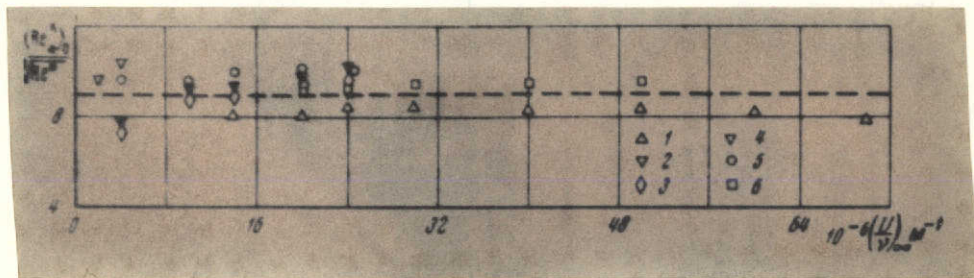
Figure 1.

produced by the boundary layer of the wind tunnel walls, or to use established terminology, the effect of the unit Reynolds number.

This parameter may be used to represent the data on the transition in the boundary layer of a plate with a finite thickness of the leading edge. It is shown that at values of b > 0.02 mm, in spite of allowance for perturbations of the

advancing flow by the introduction of the correlation parameter,
the influence of the unit Reynolds number is apparent, i. e.,
there is an interrelated influence of the model edge blunting
and the perturbations of free flow.

Excluding the influence of the leading edge blunting by
extrapolating each case to b = 0 requires numerous experiments
with variations in the value of b. Therefore, it is advantag-
eous to generalize the existing experimental data in the form
of the dependence $Re_x^* = Re^*_\cdot f(Re_\cdot)$. The experiments thus processed
are shown in Figure 2, where the numbers of the points
correspond to the table. The results of the boundary layer
transition in a plane plate obtained for different wind tunnels
in a wide range of flow parameters are generalized with a
scatter of 15% (the scatter boundary is shown by the dashed
curves). This scatter is apparently satisfactory, if we keep
the fact in mind that the data on the transition were obtained
by different methods. An approximation of the* dependence
makes it possible to predict the position of the transition
region in the boundary layer for the given conditions in the
range studied of parameters* only a knowledge of the
characteristics* of the walls of the wind tunnel working section
is necessary.

Thus, this interpretation of the data on transition in
a supersonic boundary layer makes it possible to assume that
the so called effect of the unit Reynolds number is due to
a group of perturbations, whose source is the turbulent boundary
layer of the walls of a wind tunnel working section and the
finite bluntness of the leading edge of the body in the flow.
The first portion of these perturbations is doubtless a
defect in the equipment and therefore their influence must be

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taken into account when analyzing the experimental data. With
respect to the perturbations produced by the leading edge, their
influence also must be taken in account. In the case of a
plane plate, the dependence shown in Figure 2 may be used.

This attempt to generalize the experimental data by means
of a correlation parameter, including the characteristics of
the boundary layer of the walls of the wind tunnel working
section, makes it possible to explain the nature of the
influence of the unit Reynolds number. However, there are not
sufficient experimental data to explain the physical
characteristics of the transition process. Further studies of
the level and the spectral composition of the entire group
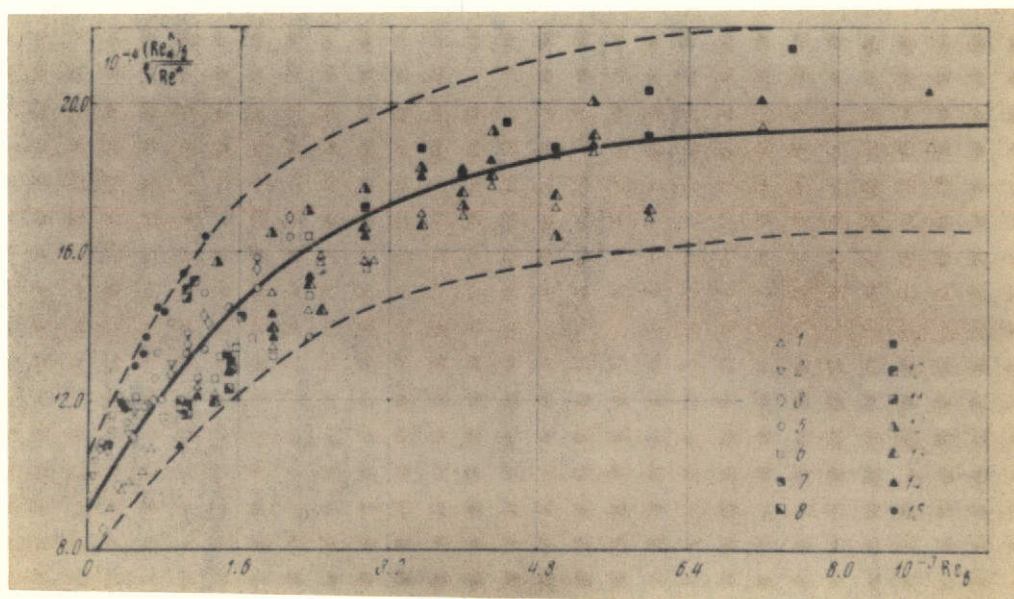of perturbations influencing the transition are necessary.

Figure 2.

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